Advanced Technology for Improving the Recycling of Black Plastics

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Abstract:

The use of plastics globally has become part of our daily life, considering that the amount of consumer plastics being used on daily basis has increased greatly over the past decays, with black plastic standing out to be the major challenge facing plastic recycling industries. The major reason for this, is that the normal near Infrared Sensors used in recycling plants cannot detect or identify carbon black plastics during plastic sorting for recycling processing.

The mid-wavelength infrared camera is a new technology that is manufactured to enable carbon black plastic recycling. The objective of this project is to study the actual feasibility of this new technology and how the technology will enable the identification of black plastics which has been a major problem facing plastic recycling Industries. The expectation from this study is to justify if the mid-wavelength infrared (MWIR) camera will put an end to the problem of unrecycled black plastics or improve plastic recycle method. Literature reviewed will be derived to investigate how municipal solid waste is generated, its impact on environmental sustainability and the mechanical recycled structure for plastic sorting from municipal solid waste. Finally, technical review of advance technology for recycling of black plastics will be justified.

Keywords:	recycled plastic, waste management, near infrared spectroscopy, Medium Wavelength Infrared camera
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LIST OF ACRONYMS AND DEFINITIONS

C&D	Construction and demolition waste
ELV	End of life vehicles
WEF	World Economic Forum
WEEE	Waste from electric and electronic equipment
MSW	Municipal solid waste
MRF	Materials recovery facility
WEF	World Economic forum
NIR	Near-Infrared Radiation
MWIR	Medium Wavelength Infrared
EU	European Union
PE	Polyethylene
PP	Polypropylene
LDPE	Low-density polyethylene
HDPE	High-density polyethylene
PS	Polystyrene
PET	Polyethylene terephthalate
PVC	Polyvinyl chloride
RIC	Resin identification code
GIS	Geographic Information system
GSM	Garbage Monitoring system

ELY Elinkeino-, liikenne- ja ympäristökeskus

UV Ultraviolet

APR Association of Plastic Recyclers

FTIR Fourier-transformation infrared spectroscopy

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1 INTRODUCTION

The response of plastic recycling globally has been effective lately with lot of new industries focusing on developing advance technologies that can help improve the quality of plastic recycling. However, the amount of plastics used on daily basis around the world keep increasing in large volumes. The amount of plastic production around the world increases from 348million tones in the year 2017 to 359million tones in year 2018 [1]. The European plastic production as of 2018 stands at about 62million tonnes. These plastics productions include commercial plastic packages such as PP, LDPE, PET, HDPE, PVC, LDPE, PS and OTHERS which are all plastics mostly found in municipal waste [2]. Despite different recycled methods or instructions implemented in developed countries to control plastic recycling the amount of plastics found in municipal waste is still on the high side. According to [1] plastic demands segment carried out in 2018 by PlasticEurope. Packaging remains the highest percentage of end use plastics. This is because apparently every consumer product found around our environment are primarily packaged with either 2D or 3D plastic. The contribution of plastic package recycling for environmental sustainability can be analysed in different majors, such as reduction of unwanted plastic waste into the oceans and other positive environmental impacts.

However, waste sorting technology is the main foundation of plastic recycling. This means that separation or sorting of plastic waste from municipal or mixed waste depends strongly on technology. Therefore, the separation of packaging waste from other varieties of waste found in municipal or mixed waste required high level of operational technology methods to succeed. The identification of packaging plastic waste in many waste industries has become very challenging especially because most of the packaging waste is produced with black plastics. Black packaging plastics are basically the major challenge facing plastic recycling plants. The reason for this, is the difficulty of traditional technology method near infrared (NIR)sensor used for plastic sorting not being able to identity packages that are made of black plastic. Recently, a new technology known has mid-wavelength infrared (MWIR) camera. The Advance technology method is basically developed to enable recycling of black plastic and improve quality of plastic recycling [3].

1.1 BACKGROUND

The problem facing plastic recycling during sorting are continuously seen around the world. Most especially when considering the negative environmental impact cause by plastic waste such as its landfill and ocean. The dependence of plastic to humanity cannot be denied, therefore plastics are found everywhere. The use of plastic materials such as polymers can be found in almost every product. Plastic dependence has impacted all sectors. The 2018 demand segment as shown in Figure 1, by PlasticEurope has proved that humanity cannot survive without plastic.

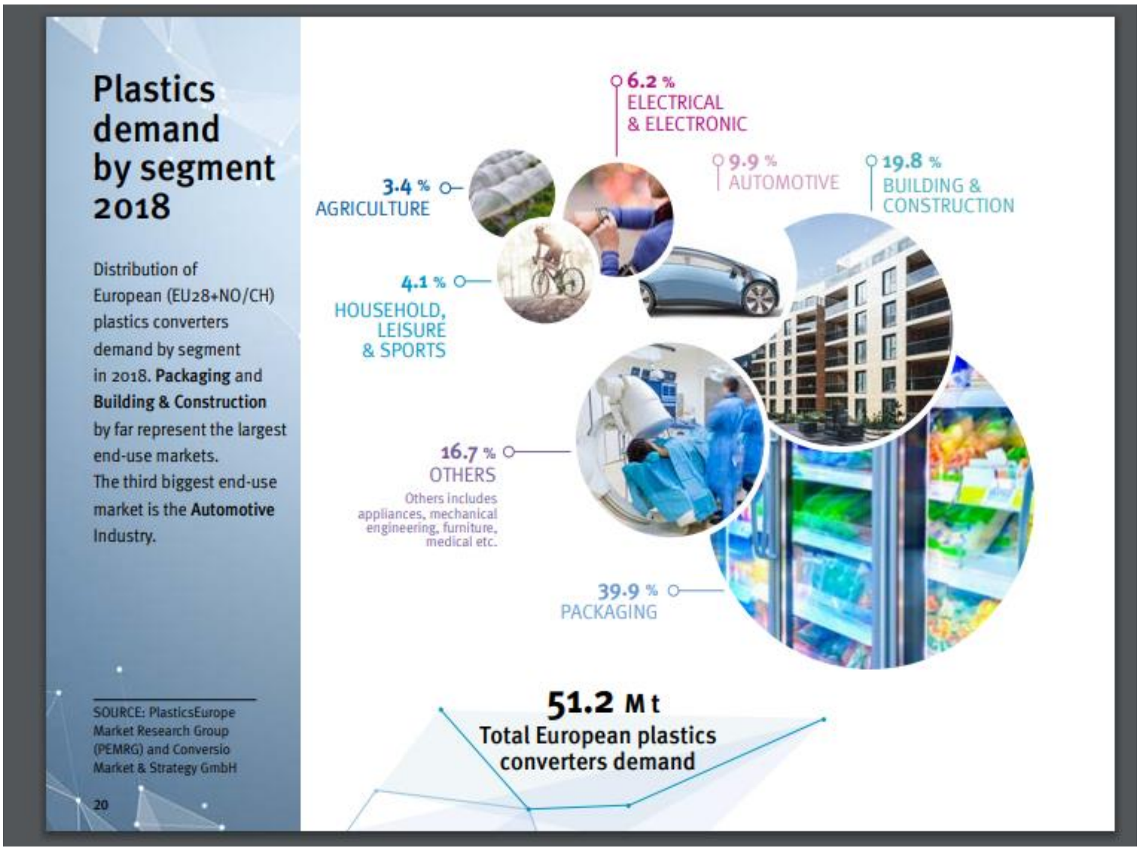

Figure 1. Plastic Europe demand segment of plastics from different sectors [1]

The segment 2018 by PlasticEurope as seen in Figure 1, as proved that the dependence of plastic is higher in packaging than other sectors. This means that packaging plastic recycling is very important issue to focus on when discussing about plastic recycling since the highest amount of plastic waste are derived from packaging.

Therefore, the cosine of this is to identify what kind of plastic are use during packaging and what kind of recycling method is in place for managing these plastic wastes. The World Economic forum (WEF) as shown in Figure 2. Simplify the most common plastic possibly to be found in municipal waste and how to identify them. According to the WEF. Plastic packaging is present in our everyday life [4]

Figure 2. packaging plastics present in everyday life *[4]*

Figure 2. by WEF is a good definition of the most common plastic found in municipal waste. Sorting of this packaging plastics from municipal waste have been successful by the help of technology. Technology plays a key role while sorting plastics by identifying the plastic based on the packaging producer responsibility law for example in Finland

(Waste Act 646/2011, section 6, paragraphs 46-67) a law that is enforced on producer to implement the waste management RIC symbols on every products [5]. This act makes every packaging production company to implement the plastics identification code on every packaging products. This makes it easier for technology sorting method such the NIR to identify packaging plastics made of different properties during recycling.

The major problem that occurs during sorting of different plastic is the challenge of Advance technology such as the NIR to recognize black packaging plastics in municipal packaging plastic waste when sorting packaging plastic waste during plastic recycling.

However, the NIR used in most industries has not been successful in Identifying the most common use packaging plastic known as black plastic. Moreover, different technology companies have been working very hard to come up with a solution that will mitigate this problem. Recently a company located in Oulu Finland (Specim) come up with a new solution that will help enable recycling for black plastic. The company introduces its new product mid-wavelength infrared (MWIR) camera a product that will possibly enhance recycling for black plastic. The company as defined this as High-speed, accurate and efficient camera specifically designed for industrial environments [6]

1.1.1 Aim and Objective

- The aim of this thesis is to discuss the type of package plastic waste found in municipal waste, the characteristics of packaging plastics, how to identify them and why they are mostly used for product packaging. The thesis will also elaborate how package plastic waste are sorted from other municipal waste with the help of technology known as NIR, and research on the new technology known as mid-wavelength infrared (MWIR) camera. The MWIR technology is recently developed to support and improve plastic recycling method by identifying black plastic that cannot be identified by normal near infrared (NIR) sensors.

Therefore, the focus of this study is to research on the following:

- What are the challenges facing plastic recycling during sorting?

- Why recycle industries have been unable to recycle package plastic wastes that are made of black plastics?
- What type of technology is used for plastics sorting to enable plastics recycling?
- Research on the mid-wavelength infrared (MWIR) camera that is developed to enable recycling of carbon black plastics.
- Justify if the mid-wavelength infrared (MWIR) camera is the solution to black plastics recycling.

1.1.2 The scope of study

The scope of this thesis is basically restricted to the major challenge facing recycle plant during package plastic sorting. A challenge that is subjected to identification of plastics found in municipal waste during sorting. A brief discussion on how package plastic is identified by visual inspection will be explained.

However, the thesis will discuss more in the technology aspect of plastic recycling. The challenge of NIR not being able to enable back plastic recycling and the contribution of MWIR spectral to enable package black plastic recycling.

Although there are several challenges facing plastic recycling in general contest such as landfill, ocean waste and other negative environmental impact cause by plastic waste. This study will only research on advance technology use in recycle industries that promotes plastic recycle and improve environmental sustainability

2 PACKAGING

The definition of packaging is defined according to the Finish Ministry of justice (FINLEX) as disposable or other product which is intended for containing or preserving material or an item, facilitating its presentation or enabling its processing, or for its transfer from the producer to a consumer or to another user [7]. These means that packaging's work hand in hand with product and cannot be abandoned. Packaging comes in different forms not only in plastics, packaging can also come in form of cardboard, rubber, and other possible materials suitable for the product.

2.1 Advantage of packaging

The importance of packaging is basically to protect the products that are ready to be distributed for human use. Package can be distributed for different purposes such as storage, sales, preserving etc. Most of the common packaging products come in boxes, bags, bottles, envelopes, wrapper, containers, and cans. Another important of packaging is that it presents the product and make it appeal to human eyes. Therefore, many companies spend lots of money in product design, because this enables product to gain more attentions through better packaging that are attractive to consumers.

2.2 Plastic packaging and their impact

Generally, packaging comes in different types depending on the purpose or focus of the product end use. Among every packaging, plastic remains the most use packaging. Plastics packaging are mainly use for packaging items that are fragile, use for preserving different food products, plastic packaging can also be found in many products uses in household. The impacts of plastic packaging are: The change in consumer habits, increased in urbanization and growing young population, increased in the use of home and personal care products, enhance the development in the field of polymer science, increased investment in food processing and production, and also increases plastic purchase by consumer and retailer [8]. However, the end use of plastics is waste, after consumer use plastics they basically end up in the waste or disposed in landfill or ocean. This result to the important of plastic waste management.

3 PLASTICS WASTE MANAGEMENT

3.1 Plastic waste sources

Generally, plastic waste comes from different sources and can be identify as post-consumer or use waste. The sources of plastic waste can be identified from the following sources:

- Construction and demolition waste (C&D)
- End of life vehicles (ELV)

- Waste from electric and electronic equipment (WEEE)
- Municipal solid waste (MSW) household or commercial waste.

The origin of the plastic waste will determine how plastic waste can be managed. However, this study will only focus on plastic waste from MSW. As seen in Figure3, Packaging stands at 39% indicating clearly that packaging has the highest plastic production demand area, the next on demand is building and construction with 20%, follow by Automotive with 7.5%, why electrical and automotive stands at 5.6%. However, studies as proved that 73% of this plastic are present in houses around EU, why the rest 27% are mainly used when distributing industrial packages.

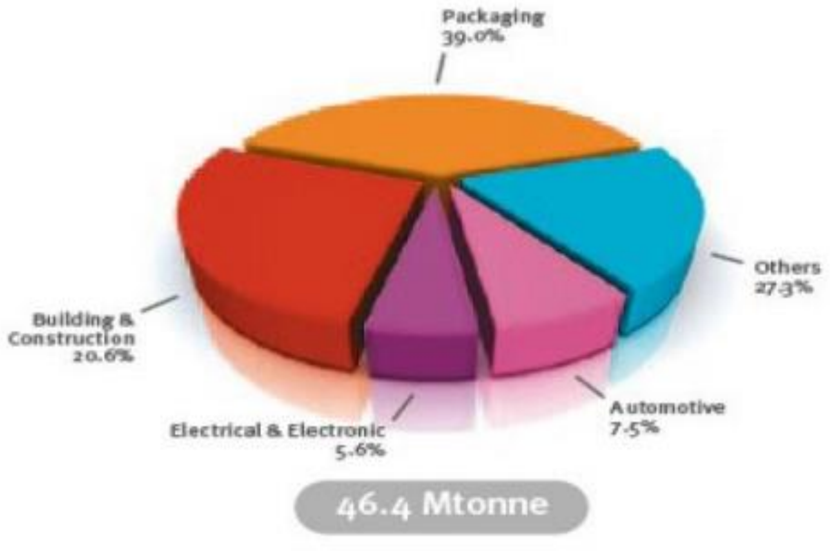

Figure 13: Industry demand by end-use sector of different plastics in the EU27+NO+CH 2010 (source: Villanueva & Eder, 2014)

Figure 3. Categories Plastic waste sources [9]

3.2 Plastic recovery or collection strategies

3.2.1 Strategies

There are different strategies put in place for the recovery of plastic. Most countries are coming up with different measures to enable sustainable plastic end use. The Ministry of Environment Finland in March 2018, proposes ten measure for Finland plastic road map the measures are as follow:

- Reduce littering and avoid unnecessary consumption
- Possibility to introduce tax on plastics
- Increase the significantly the recovery of plastics waste
- Improve the identification of plastics in building and sorting of plastics waste at construction sites
- Promote the recycling and replacement of plastics in agriculture and horticulture
- Introduce diverse recycling solution for plastic recovery
- Invest in alternative solutions and set up a new plastic knowledge network
- Raise the plastics challenge high on the international agenda of Finland

The implementation of most of these measures are already in use why some of them are on implementation processes [10]. Among the ten-proposal measure, the most effective that is in line with MSW are increasing the recovery of plastic waste and Improving the identification of plastics in building and sorting of waste which is in line with the focus of this study.

3.2.2 Plastic waste recovery or collection processes

The recovery or collection of plastics comes in different ways. These days there are different strategies applied for plastic collection. However, all these strategies can be categorized into either single or multi-stream recycling [11]

- The single stream recycling systems is a system in which household waste are gathered into one single container. After which, the waste will be collected into a recycling truck and then transported to material recovery facility MRF. The single stream recycle accommodates different type of waste materials and required strongly on advanced technology for sorting, materials such as plastic packaging in single stream are sorted with optical sensor technologies.

- Multi-stream recycling are collection methods that of waste management that implement the waste separation methods from the waste source. This means that waste is separated into two or more separate bins in such a way that it simplifies how human disposed waste. Countries such as Finland make use of this method, in almost all household in Finland waste are sorted in different bin such as cardboard, paper, aluminium, Biowaste, iron, glass, plastic, Mix waste etc [11].

Both recovery strategy has their own advantages and disadvantages. The recovery of package plastic waste can mainly be recovered from waste coming from the multi-stream recycling method. MSW waste is collected from respective Municipalities and are recycled depending on the law put in place for recycling processing in that municipality. Basically, MSW is collected from household and are transported down to MRF where the plastic waste is then separated from other municipal waste.

4 PLASTIC SORTING AND IDENTIFICATION

There are different methods used for sorting plastics throughout recycling process in other to archive the actual result. Technology and manual method use are as follow:

- **NIR**: NIR make use of wavelength spectral to identify different plastics according to their resin, this helps to specify the mechanical property of the plastic during sortation. NIR can be found in MRF and plastic reclaim places.

- **Visual sensing**: The visual sorter is a visible light with highly speed camera that helps to differentiate coloured bottles. However, this instrument does not have the capacity for identifying plastic resins.

- **Manual sortation**: Manual sortation does not apply any technology, the manual sortation is done so that reclaimers can inspect plastics visually and compare the accuracy of the sorting machines, also remove contaminants from the material stream,

4.1 MSW plastics sorting and separation

The importance of plastic sorting and separation is to promote smooth plastic recycling processing. The methods used for separation are set to separate plastics from municipal wastes.

4.1.1 Sorting and separation

Sorting and separation of plastics from waste management perspective the collection and sorting of plastics works hand in hand and can be referred to as plastics waste road map for plastic recycling as shown in Figure 4. The main objective of this method is to separate plastic from other MSW. The separation of plastics from other materials is known as composite processing.

Figure 4. plastic sorting road map

4.1.2 Polymer plastics in MSW

There are different types of plastic polymers use globally, most especially in the EU, but among all polymers, five categories of them are the most use. These polymers according to [9] dominates the market and can be found in every municipal solid waste MSW. These polymer plastics account for around 75% of the production demands. Figure4, shows the percentage of production demands for these plastics. The demand of this plastics for commercial packaging use has not changed for many years, these shows the relevance of polymers for commercial product packaging and their impact in municipal waste. The most demand plastics are as follow:

- Polyethylene (29%, including Low density polymers such as LDPE, and high-density polymers such as HDPE)
- Polypropylene (PP, 19%)
- Polyvinylchloride (PVC, 12%)
- Polystyrene (solid-PS and expandable- EPS, 8%)
- Polyethylene terephthalate (PET, 6%)

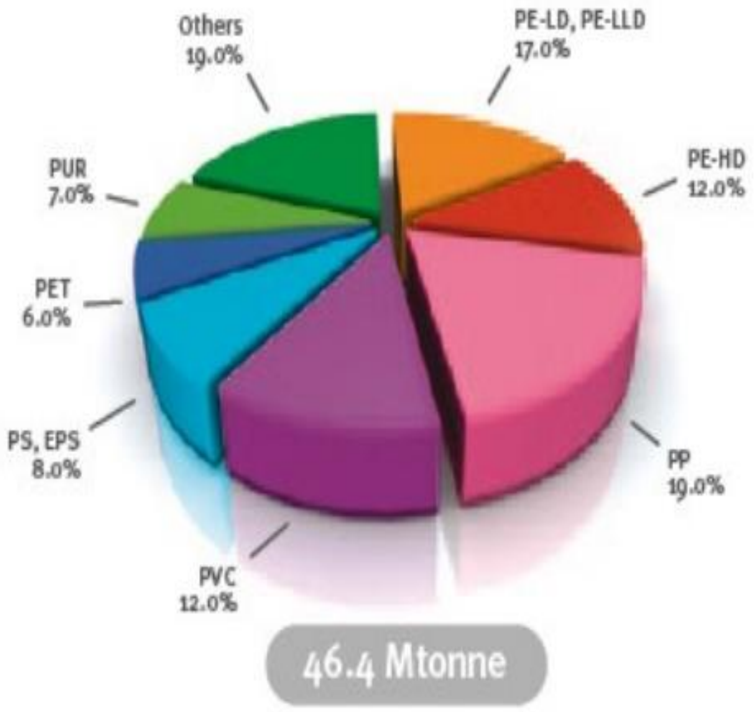

Figure 2.1. Demand by industry of different plastics in the EU27+NO+CH in 2008, by plastic type. Source: PlasticsEurope et al. 2011.

Figure 5. production demands of plastics [9]

4.2 Packaging plastic recognition

Municipal or household waste MSW comes with huge amount of plastic made of polymers. During waste sorting the plastics from municipal waste are identified according to the International Resin identification code (RIC). These are set of triangle symbols found on every plastic product. The codes are identified with different numbers. The numbers enable identification of plastics during sorting and recycling.

However, the recognition of this polymer plastics is subdivided into seven different symbols. The symbols make it easier to recognise what the plastics are made of, their properties and usage methods. When recycling plastics it is very important that the materials the plastic is made of are correctly identified. Unidentified plastic materials can create lots of problems during recycling, which can lead to poor recycle quality and affect the plastic mechanical properties [12]. Table 1, 2, shows different types of polymer plastics that are mostly found in MSW, There purpose of use and their properties. The main type of polymer plastic found in MSW are (PE, PET, PP, PS and PVC) since they are the most polymer use for plastic packaging. The main objective of the RIC identification code for sorting purpose is to enable smooth plastic sorting. This make it possible for the NIR to identify packing plastic according to their RIC symbols [9]

Table 1. The identification code of polymer packaging [9]

Table 2.2. Identification coding system of polymers. Adapted from (ACC, 2011)

Polymer name and image	Properties	Uses
PETE Polyethylene terephthalate (PETE, PET)	• Clear and optically smooth surfaces for oriented films and bottles • Excellent barrier to oxygen, water, and carbon dioxide • High impact capability and shatter resistance • Excellent resistance to most solvents • Capability for hot-filling	PET is clear, tough, and has good gas and moisture barrier properties. This resin is commonly used in beverage bottles and many injection-moulded consumer product containers. Cleaned, recycled PET flakes and pellets are in great demand for spinning fibre for carpet yarns, producing fiberfill and geo-textiles. Nickname: Polyester.
High-density polyethylene (HDPE)	• Excellent resistance to most solvents • Higher tensile strength compared to other forms of polyethylene • Relatively stiff material with useful temperature capabilities	HDPE is used to make many types of bottles. Unpigmented bottles are translucent, have good barrier properties and stiffness, and are well suited to packaging products with a short shelf life such as milk. Because HDPE has good chemical resistance, it is used for packaging many household and industrial chemicals such as detergents and bleach. Pigmented HDPE bottles have better stress crack resistance than unpigmented HDPE
V Polyvinyl chloride (PVC or V)	• High impact strength, brilliant clarity, excellent processing performance • Resistance to grease, oil and chemicals	Pipe, fencing, shower curtains, lawn chairs, non-food bottles and children's toys. In addition to its stable physical properties, PVC has good chemical resistance, weatherability, flow characteristics and stable electrical properties. The diverse slate of vinyl products can be broadly divided into rigid and flexible materials.
LDPE Low density polyethylene (LDPE) Includes Linear Low Density Polyethylene (LLDPE).	• Excellent resistance to acids, bases and vegetable oils • Toughness, flexibility and relative transparency (good combination of properties for packaging applications requiring heat-sealing)	LDPE is used predominately in film applications due to its toughness, flexibility and relative transparency, making it popular for use in applications where heat sealing is necessary. LDPE also is used to manufacture some flexible lids and bottles as well as in wire and cable applications. Plastic bags, 6 pack rings, various containers, dispensing bottles, wash bottles, tubing, and various moulded laboratory equipment
PP Polypropylene (PP)	• Excellent optical clarity in biaxially oriented films and stretch blow moulded containers • Low moisture vapour transmission • Inertness towards acids, alkalis and most solvents	PP has good chemical resistance, is strong, and has a high melting point making it good for hot-fill liquids. This resin is found in flexible and rigid packaging, fibers, and large molded parts for automotive and consumer products. Auto parts, industrial fibres, food containers, and dishware

Polymer name and image	Properties	Uses
6 PS Polystyrene (PS)	•Excellent moisture barrier for short shelf life products • Excellent optical clarity in general purpose form • Significant stiffness in both foamed and rigid forms. • Low density and high stiffness in foamed applications • Low thermal conductivity and excellent insulation properties in foamed form	PS is a versatile plastic that can be rigid or foamed. General purpose polystyrene is clear, hard and brittle. It has a relatively low melting point. Typical applications include protective packaging, foodservice packaging, bottles, and food containers. PS is often combined with rubber to make high impact polystyrene (HIPS) which is used for packaging and durable applications requiring toughness, but not clarity. Desk accessories, cafeteria trays, plastic utensils, toys, video cassettes and cases, clamshell containers, packaging peanuts, and insulation board and other expanded polystyrene products (e.g., Styrofoam)
7 OTHER Other plastics, including acrylic, fiberglass, nylon, polycarbonate, and polylactic acid, and multilayer combinations of different plastics	• Dependent on resin or combination of resins	Use of this code indicates that a package is made with a resin other than the six listed above, or is made of more than one resin and used in a multi-layer combination.

Table 2. RIC symbol (ASTM, 2014)

Resin	Resin Indentification Code-Option A	Resin Indentification Code-Option B
Poly(ethylene terephthalate)	1 PETE	01 PET
High density polyethylene	2 HDPE	02 PE-HE
Poly(vinyl chloride)	3 V	03 PVC
Low density polyethylene	4 LDPE	04 PE-LD
Polypropylene	5 PP	05 PP
Polystyrene	6 PS	06 PS
Other resins	7 OTHER	07 O

5 PLASTIC RECYLING PROCESSING AND TECHNOLOGIES

The plastic recycling process basically can be described as a process that enables the recycling of plastics from other waste materials. The sorting of plastic recycling process starts from MSW generated from households, down to the sorting places known as the residual waste treatment facilities (RWTF) where different technologies are used to facilitate the sorting out of the plastics from other waste materials before recycling. To promote environmental sustainability different types of technologies has been developed to enable waste management, meanwhile the choice using these technologies depends on different country's economic status and priorities. Many developed countries such as European countries are expressing the zero-waste method, by making use of advanced technologies for the collection, sorting, storage and incrementing of MSW [13].

5.1.1 Waste collection Technologies

The collection of Municipal waste MSW, and its transportation required many technical processes, innovative technologies such as underground collection technology system, Web based GIS technologies, waste been monitoring GSM and waste compactors are used in many model countries to facilitate waste transportation [13]. However, in Finland the collection of waste is done by different waste management companies with the observation of the Finnish Law 659/1996 that covers the transport of waste within Finland. The collection or transportation of waste must be reported to the National waste Registered that is managed by the regional ELY centres, and every waste collector must have a permit issued to them by the authorities. The permit will, therefore, depend on the type of waste the collector is permitted to transport. [14]

5.1.2 Waste transportation with Trucks Technology

Most countries around the globe use this means of transportation to transport waste from municipalities to RWTF. Majority of the truck use has high technology inputs that enable them to collect huge capacity of waste by hydraulic compressors that can enable them to carry more waste compared to normal flat trucks. Waste collecting trucks has also experienced continuous developments that increase sustainability during transportation. Most of the trucks come with low fuel consumption which makes them eco-friendly. Also, continuous research is in progress for developing electric trucks in other to eliminate gas emission during waste transporting [13].

5.2 Sorting and separation Technologies

When MSW is collected and delivered to RWTF the next step is sorting and separation of different waste materials for continuous recycle processing. One of the most sorting methods used in many waste management facilities is the use of the Optical sensor sorting Technology.

5.2.1 Optical sorting Technology

This technology has been introduced many years ago and has been gaining attention from different country applying it to improve their waste management strategies. Different types of waste such as plastics, composites, and other waste have been successfully sorted with the help of sensitive optical camera known as the UV sensors and infrared spectroscopy [13]. The NIR has helped to identify different waste components according to their properties.

5.2.2 Near infrared Sensor Technology

The NIR played a significant role when sorting MSW waste. This technology has also helped to enable plastic recycling processes. In the past decades, the sorting and identification of plastics from MSW are done manually which makes it very difficult for plastic recycling. As we know that before recycling any plastic it is important to identify what the plastic is made before embarking on recycling processing.

The NIR has made it very easier to identify plastics and enable smooth recycle process. The NIR works in an automated sorting method by specifying the characteristic of plastics without any surface treatment.

5.2.3 Sorting of plastics using NIR technology

All plastics are sorted at the MRF. NIR works by identifying plastics according to their RIC codes located in the body of every packaging plastics found in the MSW. The RIC codes enable the NIR to specify the property of different plastics and separate the packaging plastics according to their RIC group. During the identification lights from an incandescent bulb is reflected on the Materials found in the MSW. The plastics are identified by the diffuse reflectance of the light back to the receiver, which is sensitive to the near infrared part of the spectrum [15]. After which the plastics are separated by their different curve fingerprints, by using state of the art machine learning algorithms [15]. The NIR has a very high accuracy technique for sorting different packaging plastics regardless of their packaging colours.

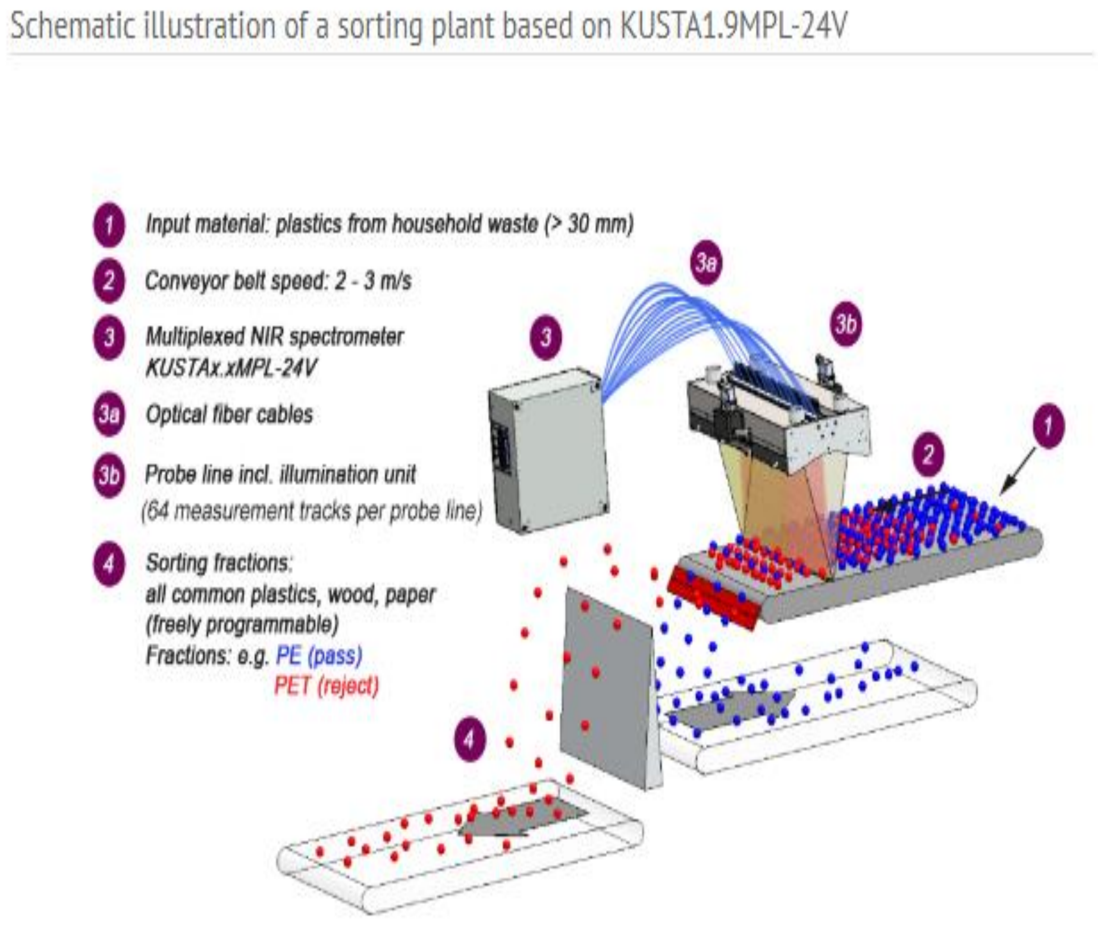

Figure 6. Example of waste sorting machine and its components [16]

5.2.4 NIR sorting at plastic reclaim canters

Sorting of plastics at reclaim canters such as shops and markets and other reclaim canters operates in a different way than sorting of plastics at the MRF. In the reclaim canters two different recycling processes approaches are used for sorting plastics, the first is the whole container processing and flake processing. This works in a way that a granulator sits in between the two stages and create separation from both packages. The NIR is designed in reclaim canters to identify one resin code, so basically the NIR is designed to remove contaminants plastics or plastics that are not identified in other to improve plastic quality when supplying huge capacity of plastic [17].

5.2.5 Advantage of NIR for plastic packaging sorting

The advantage of the NIR is that the optical sensors and scanners can identify plastics among other materials found inside MSW, not only that it can identify packaging plastics, it can also sort them more accurately by specifying them according to their resin. This means that the NIR identifies the seven RIC codes place on different packages as shown in Table 1,2. The NIR has also helped to speed up plastics packaging sorting from huge amount of waste capacity and enable fast recycle processing.

The NIR has proved to be very efficient mechanical technology for plastic packaging sorting and can also separate plastic in collection points where random plastics are put into machines. The NIR put the plastic in different category that makes it easy for further recycling process.

According to [15] in the nearest future NIR technology can help convert plastic waste into renewable resources and reduce waste pollution. [15] claims that this as already been experimented on textiles and they are excited with what the future solution will mean to plastic recycling.

5.3 Challenges of plastic recycling using NIR

The NIR is built to identify plastics according to their RIC cords, regardless of that there are different challenges that have been investigated during plastic sortation with the NIR. Packaging as discusses have a huge percentage in MSW, packages come in different shapes and colours, this makes them appear in different form. During plastic sorting, the NIR tends to identify this plastic packaging regardless of their shape, sizes, or colours. The NIR can see through different colours but some identifications cannot be identified due to different challenges.

5.3.1 Bad Labels & shrink sleeve challenges during sorting

Bad label pattern and shrink sleeve are very much in use in product packaging. For example, many bottles found in MSW comes with label and sleeves that are not made with polymers, some of these labels come inform of papers and other materials that are not same with the bottle. As a result of this, the NIR machine in most cases cannot be able to identify the polymer the bottle is made of. Therefore, if the bottle is unidentified the machine will direct the bottle to a wrong channel, or to waste plastic reclaiming facility.

In other to avoid this problem, the plastic APR label design guild that enables plastic recycling has recommended that plastics sleeves should be tested in cases whereby the plastic sleeves cover more than 70% of the bottle surface. This should be done to determine if the label interferes with NIR during plastic sortation. Therefore, it is very important that production companies follow, s the APR label guidance when making use of label sleeve that covers more than 75% of their product, to ensure that the label will not prevent the bottle from sorting [18].

5.3.2 Problem with black plastic identification

Recycling of black plastic has become major challenge. This is due to the difficulty that occurs during plastic sorting. The NIR system used at many recycling plants cannot identify packaging plastics that are made with black pigment. This is due to carbon black plastic appears to be invisible to the UV spectrum due to the plastic colour.

This made black packaging plastic ends up unsorted and unrecycled, they are however used for landfill or to generate energy. Carbon can mostly be from food packaging and can also be found in many other packaging which makes them end up in MSW. Research has proved that carbon black plastic has a big contribution in plastic packaging waste. Demark project report by plastic zero as shown that Carbon black plastic account for 10-15% plastic waste in Denmark [19] the reason for this are:

- Carbon black plastics are cheap, and so industrial demand for carbon black plastic is higher than other plastic
- Carbon black plastic has good properties that enable them easy to mix and they have good UV barrier properties.
- Carbon black is very common among food packaging.
- Consumers find carbon black plastics attractive and presentable; consumers are not aware of the challenges related to black plastic packaging.
- Carbon black plastic light weighted and durable materials

This black plastic packaging is hard to recycle.
Image: WRAP

Figure 7. Black packaging plastic

However, carbon black plastic remains very hard to recycle and has become one major challenge for plastic recycling. Some black packaging plastics appear in the shops as recyclable plastics yet the technology that enables the recycle cannot identify them during waste
sorting. Therefore, many organizations are using different platforms to encourage consumers to avoid the use of black plastics because of its environmental negative impact.

The project carried out by [20] uses different approaches to investigate colorant polymers such as alternative spectroscopic techniques, physical sorting methods, detectable markers and the alternative colorant, to see if carbon black can be detected with NIR among other colorant packaging polymers.

Table 3. NIR spectroscopy result in detecting polymer black and colorant [20]

	Detectable with NIR Spectroscopy?			**Average Recognition Rate**		
Polymer/Colourant	**PET**	**PP**	**PS**	**PET**	**PP**	**PS**
Sicopal K0095	✓	✓	✓	100%	100%	96.7%
Lumogen FK4210	✓	✓	✓	98.9%	100%	98.3%
Carbon Black UN MB	X	X	X	0%	0%	0%
Colour Tone IRR 95530	✓	✓	✓	97.6%	100%	Not tested
Colour Tone IRR 95550	✓	✓	✓	100%	Not tested	Not tested
ColorMatrix Dye Black-5	✓	✓	✓	100%	Not tested	Not tested

As seen in table 3, the summary result of other packaging made of colorant and carbon black plastics were all tested with NIR. The result proves that the NIR can detect colorant pigments that are mix with black pigment, but the carbon black plastics are completely unrecognized or detected by NIR. This means that black packaging plastic remains the major problem in plastic polymer sorting plant canters.

5.4 MWIR technology for plastic Recycling

The Medium Wavelength Infrared (MWIR) is a camera that provides a very highly sensitive and contrast with very low noise and is good for long range imagining with high temperature radiometry. MWIR just like NIR has been used for different purposes such as Lab research, use for airport perimeter security and offers researchers the possibility of investigating the properties of different materials, also fulfilling the most precise testing through ultra-low noise with accurate temperature measurement.

The MWIR, was recently discovered as a possible technology that will help in eliminating the problem with black plastic Recycling. A technology company in Finland developed MWIR camera based on advanced technology that will help improve plastic recycling and promote environmental sustainability.

6 TECHNICAL REVIEW OF NIR AND MWIR

The experiment carried out by [21], The research focuses on reviewing a comparison and demonstrating how NIR and MIR work using photon up conversion in identifying black polymers. The research proves the possibility of MIR for black plastic identification.

The NIR as know are widely used in recycling plant because it is fast and suitable for identifying different coloured polymer but could not identify black polymer because the back polymer blocks the UV light from its spectral region. On the other hand, the Spectroscopy in the MIR spectral region has the possibility to see true carbon black polymers. The MIR spectral is not fast and cannot be used to sort huge capacity of MSW, but the photon contrast technology is fast and active enough to sort huge capacity of black plastic.

6.1 The NIR spectral

The NIR spectrum wavelength can sustain within the range of 780 to 2500nm, which leads to a wavenumber range between 12,800 to 4000cm^{-1}. The NIR can be divided into two parts when analysing its wave ranges. The small near infrared (SNIR) which wavelength is from 780 to 1050nm, and the classical near infrared (CNIR) which ranges from 1050 to about 2500nm wavelength. The identification of plastic with the NIR is based on stretching vibration mode within the CH, CH_2 and CH_3, which is about 1.1 and 1.25µm, indicating the first overtone, why the second overtone range between 1,65 and 1,7µm. The wavelength range and overtone range are insufficient to pass through black carbon plastics [21].

6.2 The MIR spectral

The MIR spectral region spreads within the range of 4000 to about 600cm^{-1}. Why its wavelength region is from 2.5 to about 16 µm. The MIR has additional vibrational modes which include deformation, rocking and twisting, this is due to their molecular structures, apart from the C-H group, the MIR has other structures like the O-H, N-H and O-C this effect on the additional vibrational mode the MIR has. The additional modes enable the MIR spectral to have a unique spectrum of each polymer in the spectral range between 2500 and 600cm^{-1}. The fundamental characteristic of the MIR spectral range enables the measure and identification of carbon black polymers [21].

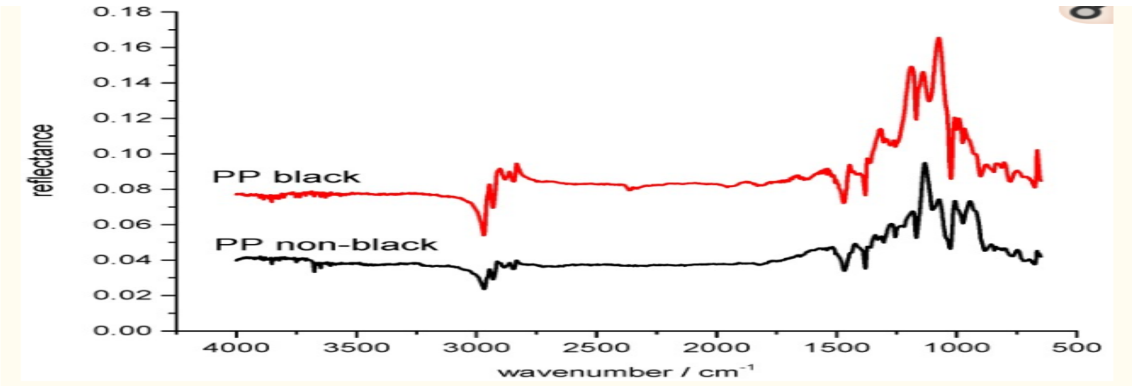

Figure 1
Comparison of IR spectra of the surface reflectance of a black and a non-black polypropylene (PP) plastic part.

Figure 8. MIR spectral on black and non-black plastics [21]

6.2.1 Sorting of carbon black plastics using MIR

The MIR, as shown in Figure8, proved that it can identify Carbone black plastic due to its wide spectral wave and wavelength range. However, black packaging plastics come in different polymer resin properties. The recycle of black plastics should be sorted according to the RIC code shown from Table 1,2. Which separates package black plastics according to their properties. The ability of MIR for black plastic sorting has been experimented by (K. S. a. M. K. Wolfgang Becker) [21]. The experiment was done by investigating the spectral reaction of different black plastics using Fourier-transform infrared spectroscopy (FTIR) and LITRAN to identify polymer type. The experiment was carried out on black PE (polyethylene), PP (polypropylene), PA66 (polyamide 66). As shown in Figure 9,10,11.

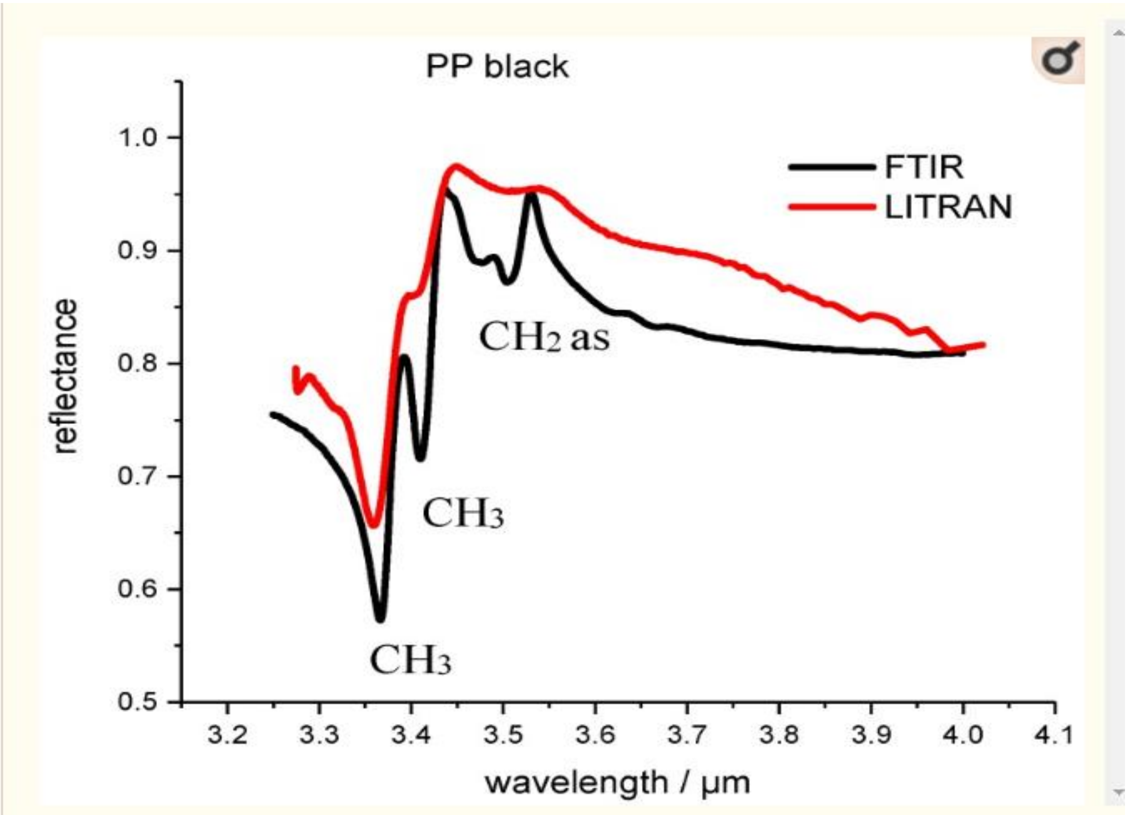

Figure 9. PP FTIR and LITRAN evaluation for plastic identification [21]

Figure 9, From the graph the result shows that the (PP) LITRAN reflectance peaks up to almost 1 above the FTIR.

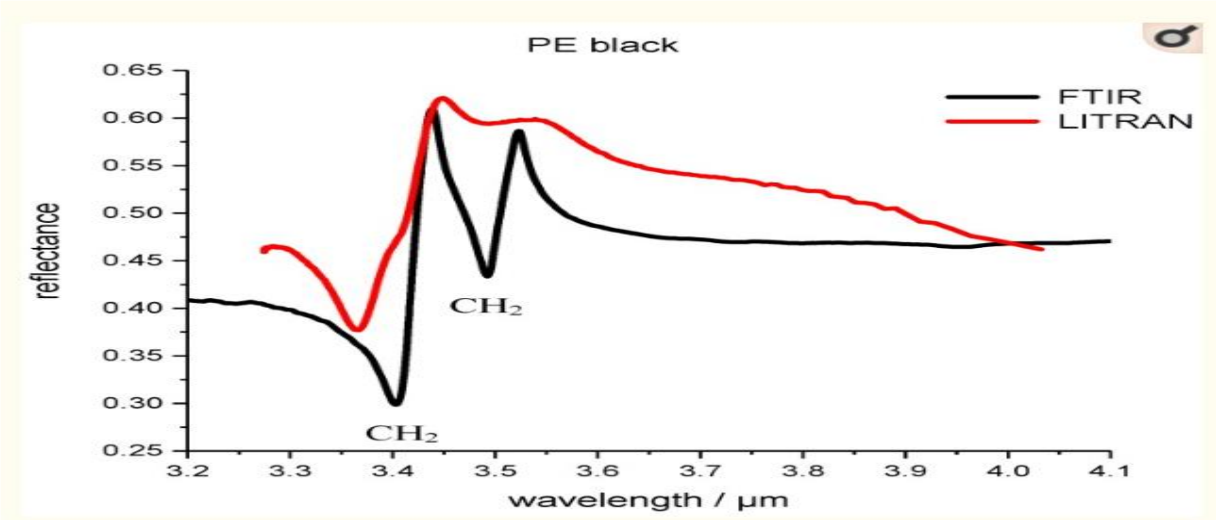

Figure 10. PE, FTIR and LITRAN evaluation for plastic identification [21]

In Figure 10, The LITRAN black (PE) spectra reflectance peaks up to 0.65 a little bit above the FTIR comparing it to the LITRAN black PP spectral.

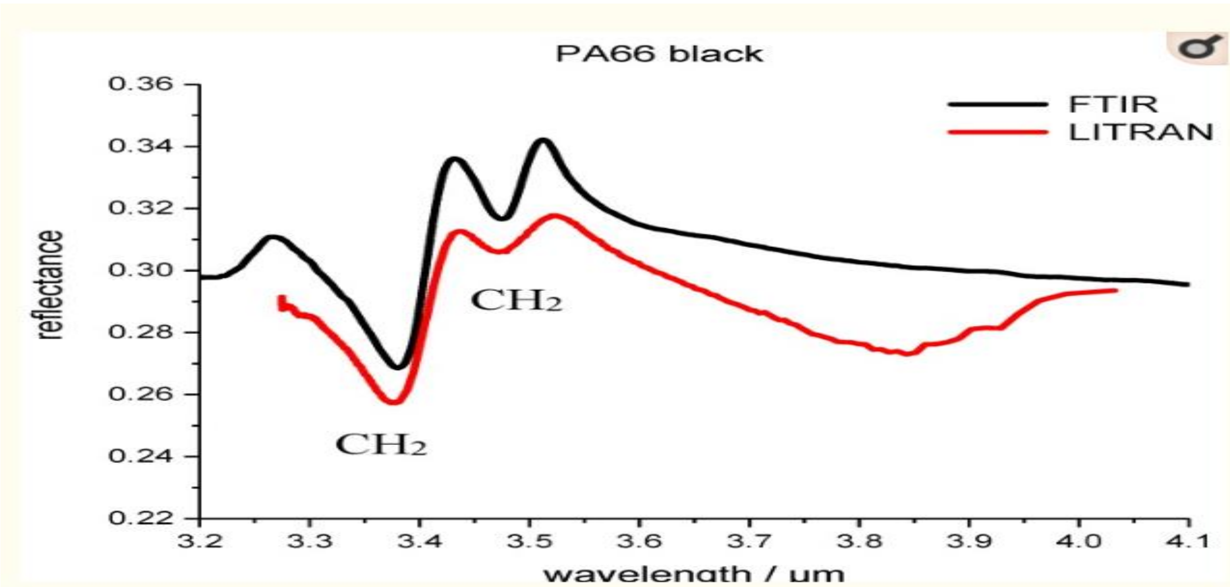

Figure 11. PE FTIR and LITRAN evaluation for plastic identification [21]

As shown in Figure 11, the FTIR and LITRAN spectrum of PA66 indicates a very different curve. The LITRAN spectral PPA66 reflectance peak was about 0.30 and was below the FTIR.

The result from the research demonstrated clearly how MIR can be used for black plastics sorting. When looking at the graphs from Figure 9,10,11. There are clear differences that occur in the FTIR and LITRAN. The graphs from figure 9,10, and 11 shows differences in the reflectance values whereby PP reflectance value is 1mm, why the PE reflectance value peak up to 0.65 and PA66 reflectance value peak up to 0.30. This means that the MIR is suitable for packaging black plastics sorting and also offers the possibility to expand existing sorting systems within NIR sorting into the MIR range [21]. This is good because the sorting of packaging black plastics is done in huge MSW, to engineer both NIR and MIR on same plant will enable fast sorting method for smooth recycling.

6.3 Technical Differences of NIR and MIR

Table 4. Technical comparison of NIR and MIR

	Wavelength range µm	**Spectral region**	**Molecular structure group**
MIR	2.5 - 16 µm	600 – 4000 cm^{-1}	C-H, O-H, N-H, and O-C
NIR	1.1 – 1.25 µm 1,65 - 1,7µm	780 – 2500nm	CH, CH_2 and CH_3

Table3, gives a good technical review comparison of NIR and MWIR, from the table it is clear that the NIR wavelength range max is 1,65 - 1,7µm is which is lower compared to that of MWIR 2.5 - 16 µm, the same can be seen in the spectral region they both covered the NIR spectral region spread within 780 – 2500nm, why the MWIR 600 – 4000cm^{-1} spectral region spread more than the NIR. However, similar comparison can be seen from their molecular group as shown in Table 3. The advantage of the MWIR is that it contains a wider spectral region, stronger wavelength, and also the MWIR contain additional molecular structures with different vibration tone, all of these fundamental characteristics give the MWIR the ability to identify carbon black plastics. Also, the MWIR has good quality in identifying different carbon black plastics during sorting. However, the MWIR will help to improve packaging plastic recycling and solve the major challenges with NIR during plastic recycling.

7 DISCUSSION AND CONCLUSION

This study elaborates through the importance and impact of technology in waste management most especially in waste separation. The study also discusses the increase of plastic during the past decade up to this day, it has been proved also that the increase percentage of plastics around the globe is not fading off anytime soon, considering the rate of plastic increasement within the last decade. Although there are many articles and blogs out there advocating for zero plastic usage. The study has also proved that among all plastic production demand, packaging plastic production demands is 39%. This means that packaging is the most produce plastic in the plastic industries. This leaves us with fact that packaging has a huge impact in MSW. However, the outcome of this study has been subjected to how plastics are been sorted out from municipal waste, the challenges of plastic recycling, and the contribution of the new technology in enabling black plastic recycling.

The study proved the difficulty in most polymer sorting plant in identifying black packaging plastic. While analysing the situation many NGOs is using their platform to discourage consumers not to buy products that are package with black plastics, due to its recycling difficulty. An approach many thinks can help to promote polymer plastics sustainability. It is therefore very clear that black packaging plastic is the main problem in plastic recycled canters.

The comparison of fundamental characteristics between the NIR and MIR, has explained the reason why the MIR can solve the problem of black plastic recycling, a problem that has been in existence for many decades, when technically reviewing the result in Table 4, it shows that the NIR wavelength ranges within 1.1 – 1.25µm, why the MIR wavelength ranges within 2.5 - 16µm, also the MIR spectral region can spread up to $4000cm^{-1}$, why the NIR spectral region can only spread up to 2500nm, finally the molecule structure group between both tools are different. All these differences have proved that the MIR has stronger wavelength to exceed the blackness of carbon black and its spectral region stands at is advantage to identify carbon black plastics.

The MIR on the other hand can identify black plastics, but the sorting of black plastics is another challenge, because black packaging plastics comes in different RIC resin properties. The research done by (K. S. a. M. K. Wolfgang Becker) [21], has proved that the MIR also has the capacity of sorting and identifying different black plastic according to their RIC resin properties. This result as we can see in Figure 9,10 and 11 was carried out on PP, PE and PA66 BLACK, the analysis was archived by comparing the spectra and LITRAN range of this black plastic. At the end, it can be justified that the MIR is very well suitable for sorting and identifying black plastics, because all the three black plastic use for the experiment came out in different spectral and LITRAN ranges.

Finally, the conclusion from this is that MIR has proved to be good solution approach to black plastic recycling. Because it enables identification of black plastics and can sort black plastics according to their RIC group. This proves that the MIR can put an end to the challenges facing most recycling industries, whereby the NIR cannot identify black plastics during sorting and identification. However, NIR is more widely use and accepted in recycling industries. Despite the advantages of the MIR and its ability to put an end to the problem of black plastic recycling. The question that arises during this study is why is it not yet in use in plastic sorting facilities? Also, the recycling plastic plants are slow in implementing this technology into their recycling sorting facilities. The reason behind the slow acceptance of MIR by recycling industries can probably be due to the cost of the MIR or may also be because recycling sorting facilities are very much comfortable with the NIR. However, to archive the aim of sustainable plastic waste management it is important that the government implement more support for the recycling of black plastic or support NGO,s in creating awareness on the negative environmental impact created by black plastics in such a way that consumers can understand the consequences of black packaging plastic to our environment, knowing very well that black plastic has a huge impact in MSW waste and needed to be recycled to promote environmental sustainability.

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APPENDISES

Appendix 1

The RIC identification code was initiated by the society of plastic industry to identify plastic packaging materials. The identification code is found in Table 1and 2.

Table 2.2. Identification coding system of polymers. Adapted from (ACC, 2011)

Polymer name and image	Properties	Uses
1 PETE Polyethylene terephthalate (PETE, PET)	• Clear and optically smooth surfaces for oriented films and bottles • Excellent barrier to oxygen, water, and carbon dioxide • High impact capability and shatter resistance • Excellent resistance to most solvents • Capability for hot-filling	PET is clear, tough, and has good gas and moisture barrier properties. This resin is commonly used in beverage bottles and many injection-moulded consumer product containers. Cleaned, recycled PET flakes and pellets are in great demand for spinning fibre for carpet yarns, producing fiberfill and geo-textiles. Nickname: Polyester.
2 High-density polyethylene (HDPE)	• Excellent resistance to most solvents • Higher tensile strength compared to other forms of polyethylene • Relatively stiff material with useful temperature capabilities	HDPE is used to make many types of bottles. Unpigmented bottles are translucent, have good barrier properties and stiffness, and are well suited to packaging products with a short shelf life such as milk. Because HDPE has good chemical resistance, it is used for packaging many household and industrial chemicals such as detergents and bleach. Pigmented HDPE bottles have better stress crack resistance than unpigmented HDPE
3 V Polyvinyl chloride (PVC or V)	• High impact strength, brilliant clarity, excellent processing performance • Resistance to grease, oil and chemicals	Pipe, fencing, shower curtains, lawn chairs, non-food bottles and children's toys. In addition to its stable physical properties, PVC has good chemical resistance, weatherability, flow characteristics and stable electrical properties. The diverse slate of vinyl products can be broadly divided into rigid and flexible materials.
4 LDPE Low density polyethylene (LDPE) Includes Linear Low Density Polyethylene (LLDPE).	• Excellent resistance to acids, bases and vegetable oils • Toughness, flexibility and relative transparency (good combination of properties for packaging applications requiring heat-sealing)	LDPE is used predominately in film applications due to its toughness, flexibility and relative transparency, making it popular for use in applications where heat sealing is necessary. LDPE also is used to manufacture some flexible lids and bottles as well as in wire and cable applications. Plastic bags, 6 pack rings, various containers, dispensing bottles, wash bottles, tubing, and various moulded laboratory equipment
5 PP Polypropylene (PP)	• Excellent optical clarity in biaxially oriented films and stretch blow moulded containers • Low moisture vapour transmission • Inertness towards acids, alkalis and most solvents	PP has good chemical resistance, is strong, and has a high melting point making it good for hot-fill liquids. This resin is found in flexible and rigid packaging, fibers, and large molded parts for automotive and consumer products. Auto parts, industrial fibres, food containers, and dishware

Polymer name and image	Properties	Uses
6 PS Polystyrene (PS)	•Excellent moisture barrier for short shelf life products • Excellent optical clarity in general purpose form • Significant stiffness in both foamed and rigid forms. • Low density and high stiffness in foamed applications • Low thermal conductivity and excellent insulation properties in foamed form	PS is a versatile plastic that can be rigid or foamed. General purpose polystyrene is clear, hard and brittle. It has a relatively low melting point. Typical applications include protective packaging, foodservice packaging, bottles, and food containers. PS is often combined with rubber to make high impact polystyrene (HIPS) which is used for packaging and durable applications requiring toughness, but not clarity. Desk accessories, cafeteria trays, plastic utensils, toys, video cassettes and cases, clamshell containers, packaging peanuts, and insulation board and other expanded polystyrene products (e.g., Styrofoam)
7 OTHER Other plastics, including acrylic, fiberglass, nylon, polycarbonate, and polylactic acid, and multilayer combinations of different plastics	• Dependent on resin or combination of resins	Use of this code indicates that a package is made with a resin other than the six listed above, or is made of more than one resin and used in a multi-layer combination.

Resin	Resin Indentification Code-Option A	Resin Indentification Code-Option B
Poly(ethylene terephthalate)	1 PETE	01 PET
High density polyethylene	2 HDPE	02 PE-HE
Poly(vinyl chloride)	3 V	03 PVC
Low density polyethylene	4 LDPE	04 PE-LD
Polypropylene	5 PP	05 PP
Polystyrene	6 PS	06 PS
Other resins	7 OTHER	07 O

Appendix 2

Table 3 displayed the identification of black colorants plastics detected by NIR, a research don by Wrap. The research was carried out on PET, PP, and PS [20]

	Detectable with NIR Spectroscopy?			Average Recognition Rate		
Polymer/Colourant	**PET**	**PP**	**PS**	**PET**	**PP**	**PS**
Sicopal K0095	✓	✓	✓	100%	100%	96.7%
Lumogen FK4210	✓	✓	✓	98.9%	100%	98.3%
Carbon Black UN MB	X	X	X	0%	0%	0%
Colour Tone IRR 95530	✓	✓	✓	97.6%	100%	Not tested
Colour Tone IRR 95550	✓	✓	✓	100%	Not tested	Not tested
ColorMatrix Dye Black-5	✓	✓	✓	100%	Not tested	Not tested

Appendix 3

Table 4 displayed a technical review of the spectral differences between the MIR and NIR, a review that explained the feasibility of the MIR in sortation of black packaging plastic.

Table 4, Technical comparison of NIR and MIR

	Wavelength range µm	**Spectral region**	**Molecular structure group**
MIR	2.5 - 16 µm	600 – 4000 cm^{-1}	C-H, O-H, N-H, and O-C
NIR	1.1 – 1.25 µm	780 – 2500nm	CH, CH_2 and CH_3